The Economics of Linen Nets: A Solution to the Microplastic Waste Problem in Waters

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Tiivistelmä/Referat – Abstract

Oceans, seas, lakes and other waterbodies are increasingly suffering from too much plastic waste. Numerous sources are contributing to this plastic waste problem. Additionally, conventional fishing nets, made out of nylon, are causing environmental damage by disintegrating into microplastics. The breakdown process stops there, as these microscopic particles are non-biodegradable. Microplastics remain in waters for years causing harm to marine organisms that ingest them. Linen fishing nets are a valid alternative and more ecological production of nets. This study aims to compare the costs of these new linen nets with conventional nets. These costs can be related to the environmental benefits of these alternative nets.

The research objective is to study the question under which conditions it would be optimal to choose linen nets over conventional (nylon) fishing nets. The conditions examined are economic and policy, environmental and technological. This research question is put into the wider context of microplastics. A rotation model, typically used in forest economics, is applied to analyze the optimal lengths of periods to renew both a linen and a nylon fishing net. A comparison of the costs is conducted and a subsidy-based policy instrument is determined for the fishers using linen nets.

A subsidy-based policy could be applied to make fishing enterprises in Finland use ecological fishing gear. The results suggest that the costs of such a policy would be reasonable, estimated between €1.1 and €4.5 million in this study. Importantly, an increase in the use of ecological nets would lead to a decrease in the total microplastic load in waterbodies.

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Tiivistelmä/Referat – Abstract

Maailman vesistöjen muoviroskakuorma lisääntyy huolestuttavan nopeasti. Valtameret, meret, järvet ja joet kohtaavat tämän valitettavan ongelman. Yksi suurimpia ongelman aiheuttajia ovat mereen hylätyt kalastusverkot, jotka vuosien mittaan hajoavat mikroskooppisen pieniksi partikkeleiksi. Tällöin ne luokitellaankin mikromuoveiksi. Hajoamisprosessi kuitenkin loppuu tähän pisteeseen, ja näin ollen nämä mikromuovit aiheuttavat haittaa ympäristölle. Monet eliöt nielevät näitä hiukkasia luullen niitä ravinnoksi, ja tämä johtaa varsinkin simpukoissa kehitys- sekä lisääntymishäiriöihin. Pellavasta tehdyt kalastusverkot ovat varteenotettava ratkaisu vesistöjen mikromuoviongelmaan. Työn tavoitteena on kalastusverkko-ongelman tarkastelu eri näkökulmista painottuen ekologisten verkkojen kustannustekijöihin sekä tukipolitiikkaan, jolla kalastajia kannustettaisiin vaihtamaan muoviverkot esim. pellavaverkkoihin.

Osana laajempaa mikromuoviongelman tarkastelua tarkempi tutkimuskysymys tässä työssä liittyy siihen, mitkä taloudelliset ja poliittiset, ympäristö-, ja teknologiset olosuhteet johtaisivat siihen, että kalastajien olisi optimaalista valita pellavaverkot nykyisten muoviverkkojen sijaan. Analyyttisestä kalastusyrityksen voiton maksimointiongelmasta johdetaan verkkojen käyttöiän optimaalinen rotaatio sekä pellavaverkkoja että muoviverkkoja käytettäessä. Mallin numeerisessa sovelluksessa käytetään Suomen ammattikalastajien tilinpitoaineistoon perustuvia tietoja vuodelta 2016. Kokonaissubventioiden määrän, jolla Suomen ammattikalastajat siirtyisivät pellavaverkkojen käyttöön arvioitiin olevan vaihteluvälillä 1.1-4.5 miljoonaa euroa. Vaihtoehtoisesti kuluttajilta vaadittavan maksuhalukkuuden tulisi tulosten mukaan olla 7.8%-9.9% korkeampi pellavaverkoilla pyydetyistä kalatuotteista verrattuna nykyisillä muoviverkoilla pyydettyihin kalatuotteisiin.

Pitkän aikavälin tavoitteena on, että pellavaverkot ovat kustannustehokkaita verrattuna tämänhetkisiin muoviverkkoihin. Vieläkin tärkeämpänä pidetään, että pellavaverkot johtaisivat mikromuovien vähentymiseen kaikissa vesistöissä.

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1 Introduction

1.1 Background

Plastics dissolving and disintegrating in waters is an increasing global problem, and everyone should take responsibility of their actions to solve it. Plastic waste is accumulating on water surfaces, along coastlines and on ocean floors. Mountains of plastic also destroy the habitats of sea animals, aquatic organisms and bird nests. In the worst case, animals become entangled in plastic bags or nets and die. Both birds and fish also ingest plastics. In addition, the beauty of many beaches has been ruined and also the availability of clean water to swim in.

Not only are plastics a problem as a whole, but the weathering of plastic products into microplastics may even more seriously damage the environment. The concentration of microplastics in the oceans has increased over the years with the increased use of plastic products (Arthur, Baker & Bamford 2009). Since microplastics consist of extremely small particles, they can infiltrate even the smallest of apertures in cells (ECHA 2018). There are differing views concerning what can be classified as nanoplastics and microplastics, but the general consensus is that these small plastic particles are no greater than 5 millimeters in length (ECHA 2018; Magnusson et al. 2016a; NOAA 2018).

Because of certain environmental conditions, plastics seem to just continuously break down into smaller particles. The amount of small plastics will increase even though the input of larger plastic debris can be decreased considerably. The smaller particles, microplastics, can stay suspended in water almost indefinitely, but they eventually settle on the ocean floors (SAPEA 2019). This microplastic debris will alter the natural biodiversity of waterbodies.

One of the biggest product groups contributing to the plastic waste problem is abandoned and discarded fishing nets which constitute a large part of the accumulated plastic garbage in waters (Lusher, Hollman & Mendoza-Hill 2017; Sebille et al. 2015). Most of them can be found floating in water. These synthetic fishing nets also dissolve and disintegrate into even smaller pieces over the years and sink into the bottom sediments therefore never really disappearing from the environment (EU Parliament 2018). Whether fishing gear is deliberately abandoned or lost unintentionally, the evidence is alarming.

It is thus important to study policies and the costs thereof that would help fishing companies to change from using synthetic fishing gear to ecological fishing nets. Another important task is to develop gear production technologies that focus on the use of natural materials. Examining the policies, specifically subsidies, and their costs is the main contribution of this study.

1.2 Previous literature

FAO has produced various publications on microplastics (Lusher et al. 2017), and on derelict fishing gear (Macfadyen, Huntington & Cappell 2009). The publication by Lusher et al. (2017) explains how fisheries and aquaculture have relied on synthetic materials for many years. They claim that derelict fishing gear is the leading object group contributing to plastic waste in waters. They define plastics and microplastics, and their pathways into the aquatic environment. They also describe the risks of microplastics to humans and marine animals that have ingested them.

In addition to FAO, several other researchers have tried to solve this problem. These studies have concentrated on the issues related to microplastics, including economic and political themes, environmental and biological concerns, and other topics such as technological advantages of linen and fishers' behavior leading to abandoned and lost gear.

Hammer, Kraak and Parsons (2012) and Kaiser (2014) observe the politics that revolve around microplastics. Macfadyen et al. (2009) and GESAMP (2015) studied both political as well as environmental aspects. Hammer et al. (2012) review the history of plastic production and human behavior related to plastic use. The authors (Hammer et al. 2012) state that the fishing industry causes the largest input of plastic debris into the marine environment. Kaiser (2014) carried out a study under the European Parliament where the author analyses the type of gear used in the fishing sector and the impact of these different types on the environment. The conflicts among fishing sectors cause loss and damage to fishing nets.

Macfadyen et al. (2009) focused on the hazards caused by this type of gear in the marine environment. They specify the reasons why fishing gear may be abandoned, lost or discarded and review current measures in place that reduce the problem. GESAMP (2015), which is a joint group of experts on the scientific aspects of marine environmental protection, released a global assessment on microplastics. This assessment describes in detail how microplastics form, the effects of microplastics on the marine habitat, and social perceptions of microplastics. They also provide policy recommendations on how to stop the formation of microplastics now and in the future.

Additionally, Derraik (2002) and Chen et al. (2018) studied environmental and biological impacts of microplastics. A review by Derraik (2002) on the pollution of the marine environment by plastic debris finds that the greatest threat of plastic debris to marine animals is caused by entanglement and the ingestion of the litter. Chen et al. (2018) studied how fishing and aquaculture activities affect microplastics in seawater, and their results indicated that 55% of microplastics were of mariculture origin.

Other research papers include those of Meenakumari and Radhalakshmi (1988), Andrady (2011), Richardson, Gunn, Wilcox and Hardesty (2018), and a book on linen by Hukkinen (1984). Meenakumari and Radhalakshmi's (1988) study is one of the few to actually examine the deterioration of fishing nets under ultraviolet radiation. The nets were exposed to UV radiation, after which the loss of mechanical properties of the nets were measured. Their study refutes the theory that there is a strong, linear relationship between the photo-oxidation with the loss in strength and extension of the nylon polymers. The correlation coefficients the authors retained are indicative of consistency.

Andrady (2011) discusses the plastics found in the marine environment and the rising concentration of microplastics. Richardson et al. (2018) studied the reasons why Indonesian and Australian fishers abandon or lose fishing gear. They found that Indonesian fishers are more prone to losing nets, and that they repair or replace damaged nets less frequently than Australian fishers.

Hukkinen (1984) has written a book on the qualities of linen and how well it functions as a textile. Of natural fibers, linen is one of the strongest. In the study by Pasila, Pehkonen, Suokannas, Hakkarainen and Pehkonen (1999) on linen, they found that linen also works well even as a construction material, but it requires immense labor, energy and high costs.

1.3 Objectives and structure

This study illustrates the damaging effects of plastics in general with an emphasis on microplastics. I discuss the role of microplastics especially in the marine environment, and the global environmental, social and economic impacts of these particles. These impacts are serious and require urgent action. Even if the production and consumption of plastics were to decrease in the coming years, the substantial amounts of currently existing plastics and new plastics that will be produced burden waterbodies. These will continue to have a long-lasting, detrimental impact on the environment as they disintegrate into microplastics.

In this study, I introduce an analytical framework to describe the behavior of private fishing companies choosing the optimal renewal times of fishing nets. This framework assumes that negative externalities arise from using plastic nets and that they could be mitigated by using linen nets. Thus, the social planner has an incentive to either tax the use of plastic nets or subsidize the use of linen nets. I focus on the latter, and apply the framework numerically using Finnish data on fishing firms and fleet from the year 2016.

The thesis is organized as follows. The first chapter provides the background information and a literature review. Chapter 2 defines microplastics and it answers the questions: *What makes microplastics a real problem? What is the danger microplastics cause?* This chapter will also identify the main sources of microplastics, with special attention on the weathering of fishing nets. Chapter 3 focuses on abandoned, discarded or otherwise lost fishing gear and considers the negative impacts of disintegrating synthetic nets. The chapter continues by introducing the fabric company Marzotto which is developing linen-based nets. Chapter 4 describes the Finnish fishing data, the theoretical framework and the numerical model. Chapter 5 provides the results and their interpretation, and chapter 6 evaluates a potential policy instrument and concludes the thesis.

2 Microplastics

To put the theoretical and empirical analysis within a wider context, I start by illustrating the problems posed by microplastics in general. This problem requires decreasing plastic production. Preventative measures are the most effective actions to stop any further build-up of plastic debris, and the formation of microparticles from new compounds entering the environment (FAO 2016). However, this would only provide a partial solution since microplastics already exist in the environment from the fragmentation of larger plastics, causing damage to biodiversity.

Plastics are remarkably widespread since their mass introduction into the markets in the 1940s up to current times (Hammer et al. 2012), and it is hard to imagine a world without them. Soon after entering the markets, plastics began to pollute the oceans, and ever since, the quantity has only increased. Most plastics are synthetic, man-made from nonrenewable raw materials and are categorically part of polymers with a great volume and weight (Järvinen 2008, 87; GESAMP 2015).

Since the 1950s, global plastic production has grown from only about 1 million tons to 322 million tons in the 21st century (Villarrubia-Gómez, Comell & Fabres 2018). An immense amount of 75,000 to 300,000 tons of microplastics per year are estimated to enter the environment in Europe alone (EU Commission 2019a).

2.1 What are microplastics?

Microplastics are any plastics classified as particles below the size of 5 millimeters (NOAA 2018). Being this small, these plastic particles can infiltrate anywhere, and many sea animals mistake them for nutrition. Multiple sources of microplastics exist but this study will focus on only fishing gear and nets. Fishing nets as a source of microplastics are categorized as a secondary source (EU Parliament 2018). This is because the plastic used in the fishing nets gradually degrades into microplastics.

The concentration of microplastics in the oceans has increased over the years and correlates with the increased use of plastic products (Arthur et al. 2009). Plastics in general cause considerable damage to the marine environment affecting the habitat, food and animal health (Wagner & Lambert 2018, 11). As a consequence, the increasing amount of microplastics in fish has increased them also in human food. However, the impact on humans is not necessarily considered a risk, according to a report by the European Chemicals Agency (EU Commission 2019a).

2.2 Primary and secondary microplastics

Microplastics can be divided into two categories depending on the origin of the source. There are either primary or secondary sources of microplastics (ECHA 2018). Primary sources of microplastics are intentionally manufactured as such (GESAMP 2015).

Microplastics are also formed as the outcome of larger plastic components disintegrating. This source of microplastics is referred to as a secondary source, since these plastic items are weathered over time (Villarubia-Gomez et al. 2018). Even many clothing and textiles these days are of synthetic origin which release microplastics while being washed (SAPEA 2019). When certain products are not recycled properly and enter the environment, the fragmentation of these products will eventually occur. The weathering of plastic items in the environment is mainly induced by UV radiation. Other causes are by wind, waves or animal contact that force the polymers to break down (FAO 2016). In the marine environment, UV radiation is the principal procedural cause of microplastics (Sebille et al. 2015). It is estimated that out of all marine microplastics, up to 81% are of secondary microplastic sources (EU Commission 2018).

2.3 Negative impacts of microplastics

Considering all waste in waters, plastic is seemingly the most tenacious and the debris with the most negative impacts (GESAMP 2015). Plastics pose many threats, since they are manufactured from fossil fuels (GESAMP 2015; Järvinen 2017, 100). The European Chemicals Agency has assessed that microplastics are resistant to full biodegradation (EU Commission 2019a). During this biodegradation process, carbon dioxide and methane are released (EU Parliament 2018; Järvinen 2008, 111). This requires aerobic conditions and may also necessitate higher temperatures that are often absent in seas and the ocean (EU Parliament 2018).

2.3.1 Environmental impacts

Microplastics have been found in all oceans, even in the remote and far away locations lacking much human activity, including Antarctica (Hammer et al. 2012). Furthermore, the deep-sea is being affected by plastic and microplastic debris. Because of the size of microplastics, they are easily transportable across waters by currents and wind (Wagner & Lambert 2018, 7). In addition, microplastics are vertically passed onto all the levels of the ocean and all the way down to the ocean floor (SAPEA 2019).

It is of growing concern that layers of the sea, even kilometers under sea level, will seriously face the consequences of human plastic consumption (FAO 2016). Once these ecosystems reach a poor condition because of macro- and microplastics (Derraik 2002), the cleaning and recovery of the deep sea levels and the ocean floor will be highly laborious to implement. These areas are hard to reach, and the ecosystem and habitat lying in them have remained untouched so far. Therefore, many endemic species will be at high risk of extinction (Chiba et al. 2018).

2.3.2 Pathways to humans

In the wild, an estimated 220 species have been found to ingest microplastics (Lusher et al. 2017). Several laboratory studies have been conducted to observe microplastic ingestion by mussels (Lusher et al. 2017; Browne, Dissanayake, Galloway, Lowe & Thompson 2008). As filter feeders, bivalves are highly susceptible to particle ingestion (Magnusson et al. 2016). Since mussels are usually commercially farmed, it is quite probable that humans will ingest microplastics too, through the food web (Chiba et al. 2018; Macfadyen et al. 2009).

Not only do filter feeders ingest microplastics, other marine species are also ingesting them by accident while feeding (Cocca et al. 2018, 131). Compared with wild-caught seafood, farmed seafood is more exposed to the uptake of microplastics (Chen et al. 2018). This higher level of microplastics in farmed fish, especially cultured mussels, may imply that microplastics originate from the structures of aquaculture (Lusher et al. 2017).

2.3.3 Socio-economic impacts

The negative impacts of microplastics extend to a societal and economic level. The degree to which humans accept plastic waste is examined from the societal perspective. In addition, the acceptable maximum amount of microplastics in the wild is considered (Galgani et al. 2010). Since the broader public is still somewhat uninformed of the effects of microplastics on marine flora and fauna, their tolerance for microplastics could be quite high.

In contrast, the economic impacts might be easier to measure. There are direct costs related to the removal of marine litter. With microplastics affecting the mortality and reproduction rate of many aquatic species (Wagner & Lambert 2018, 11), fishers will see a decrease in their stock. This will further lead to the loss of income in fisheries. Moreover, tourism in coastal areas will be affected largely because of fewer services and lower wellbeing derived from marine ecosystems (Lusher et al. 2017).

2.4 Microplastic mitigation

After World War I and World War II, the cost of producing goods with synthetic materials dropped overall (Hirvi, Kosonen, Salo & Stürmer-Hiltunen 1990). Human behavior combined with consumer demand have resulted in high levels of plastics entering the environment. The knowledge of how plastic affects the surrounding environment was not well known during the beginning of plastic production. Only after the end of the 1960s did people become more aware of and concerned about plastic pollution (Hammer et al. 2012). If this problem had been addressed already at that time, we would not be facing this adverse situation. Education and support is needed, especially in developing countries where people have limited access and resources to use newer, more sustainable products. Biodegradable products are not necessarily an answer to solving the plastic debris problem. Many bio-based plastic products have the same lifespan and durability as conventional ones (GESAMP 2015; Arthur et al. 2009).

Plastic debris and waste mismanagement is a global problem and not linked to any one nation (Hammer et al. 2012) or geographical area in particular. The complete abolishment of the plastic waste problem would require immense international work among various scientists and researchers (Derraik 2002). At the same time, to make changes to plastic production, more public attention and awareness is needed. For large and small businesses to develop new, ecological equipment, government funding and support are necessary. Furthermore, governments should update laws and policies, and reallocate taxes and subsidies (SAPEA 2019). Both the private and public sector should cooperate as well.

The plastic debris problem is difficult to solve. This problem will remain unsolved as long as new plastic debris continues to enter the oceans and seas (Hammer et al. 2012). Even if plastic production is terminated completely, the existing plastics function as a source for secondary microplastics (Magnusson et al. 2016). At this time, we still lack technological solutions to eliminate microplastic debris.

3 Fishing gear

Fishing is the livelihood of nearly 60 million people (FAO 2018), and seafood is an important source of nutrition, especially for island nations and coastal areas. Fishing and aquaculture, defined as the culturing or farming activity of certain marine species (NOAA 2019), have been exploited over time. The fishing industry, combined with other factors including climate change, is damaging the world's oceans (Kaiser 2014). If fishing gear and nets were to be managed and recycled in a proper manner, they would not be contributing to the fragmentation of macroplastic debris (Magnusson et al. 2016).

Abandoned, lost or otherwise discarded fishing gear, ALDFG, is an unfortunate root cause of many detrimental effects on the marine environment (Wilcox, Mallos, Leonard, Rodriguez & Hardesty 2016). This group is ubiquitous in oceans, seas and lakes, and is contributing to plastic waste in the marine environment (Chen et al. 2018). Furthermore, it is estimated that over 50% of microplastics in seawater results from fishing gear and aquaculture activities (Chen et al. 2018).

Since the plastic revolution of the 1950s, synthetic fishing nets supplanted most fishing gear made with natural fibers (Lusher et al. 2017). Synthetic nets were found to be more resistant in the marine environment (FAO 2016; Macfadyen et al. 2009).

3.1 Synthetically-made fishing gear

The marine industry has for some time strongly relied on lightweight plastic materials (SAPEA 2019). Early on, synthetic plastics were recognized to be resilient in the aquatic environment, cost-effective and also easy to manage owing to their lighter weight (Kim, Kim, Lim, An & Suuronen 2016). Before plastics, fishing gear was produced using natural textiles, such as linen, and other organic materials, including wood (Lusher et al. 2017).

Fishing nets, ropes, and fish lines are predominantly made out of polyamide. The general term for this plastic subgroup is nylon (Järvinen 2008, 76). These synthetic plastic materials are used to manufacture many structures in the fishing industry, including buoys that keep nets and ropes afloat (Lusher et al. 2017).

The lifespan of plastics is estimated to be up to 600 years (Macfadyen et al. 2009). This means that synthetic nets will continue to degrade for hundreds of years. The level of degradation depends on multiple factors, including UV light and water conditions (Meenakumari & Radhalakshmi 1988).

3.2 Abandoned, lost or otherwise discarded fishing gear

Fishers have a direct interest in their own fishing gear losses. The increasing amount of debris affects the quality and quantity of their catch (GESAMP 2015; Lusher et al. 2017).

The presence of abandoned, lost or otherwise discarded fishing gear in the environment may either be intentional or unintentional. The four main reasons why derelict fishing gear exists are certain enforcement pressures, operational and economic factors, spatial problems, and environmental conditions (Macfadyen et al. 2009).

Abandoned fishing nets can be associated with ownership of illegal gear or fishing that is illegal, unregulated and unreported (United Nations 2018). Fishing nets may be discarded at sea because they are damaged. Fishers may choose to discard nets over disposing of them onshore for several reasons. The main reason seems to be the lack of space in onshore disposal sites (Macfadyen et al. 2009). The primary reasons for accidentally lost fishing nets are misplacement of gear or environmental factors; for example, adverse weather conditions or disadvantageous grounds at sea (Kim et al. 2016).

Different studies seem to disagree on how much fishing gear is lost or discarded at sea on a global scale (Richardson et al. 2018; Da Ros et al. 2016). In a study by Richardson et al. (2018), the authors estimate that around 640,000 tons of fishing gear is abandoned per year. Some of the derelict fishing gear remains in the ocean, while some nets end up on shorelines (Da Ros et al. 2016), making it difficult to determine the exact number of lost gear. Montarsolo et al. (2018) estimate that derelict fishing nets contribute to over 1 million tons of plastic waste in water every year.

One study provides an estimation of the reasons why gear is lost. The tearing of nets account for 78%, while 19% of lost nets are caused by gear conflicts (Macfadyen et al. 2009). The latter arises from multiple reasons, one being that static nets are placed in a particular area of interest

(Macfadyen et al. 2009), but fishing vessels with mobile gear pass through this area. Other times, conflicts arise from competition over the same fishing zones (Kaiser 2014).

Richardson et al. (2018) studied the differences between Indonesian fishers and Australian fishers concerning their reported reasons for abandoned, lost and discarded fishing gear. Additionally, the amount of ALDFG was studied. The findings are important when examining the behavior of the Indonesian fishers. If Indonesian fishers perceived their nets to be too damaged and hence irreparable, they were more likely to discard their fishing nets. Thirty-three percent of Indonesian fishers reported discarding them. They also experienced more recurrent losses compared to the Australian fishers. In Indonesia, an over-allocation of legal fishing licenses exists provided by the government. This could be one reason why the fishers are more likely to discard their nets because of too much competition and too little income for their catches.

Abandoned, lost or otherwise discarded fishing gear poses many threats to marine life as well. Fishing nets act as a secondary source of microplastics through the degradation of the equipment (Villarubia-Gomez et al. 2018). Although many nations do have more control over the purposeful abandoning or disposing of fishing nets, other countries do not (Da Ros et al. 2016). Not only is ALDFG harmful to the aquatic habitat of these unregulated countries, ALDFG is increasingly recurrent in even the most remote geographic areas. In Alaskan waters, located far from urban areas, most of the accumulated plastic debris consists of fishing gear (Derraik 2002). Out of all plastic debris in oceans, the total amount derived from fishing gear ranges between 50% and 90% (Hammer et al. 2012).

3.3 Degradation of synthetic nets

3.3.1 Causes of fishing net degradation

A study conducted in 2018 showed that up to 46% of the plastics collected from the Great Pacific Garbage Patch were derelict fishing gear (Lebreton et al. 2018). Out of all marine debris, fishing equipment is potentially the most hazardous. First of all, derelict fishing gear poses harmful risks to marine wildlife, because many sea mammals and fish become entangled in it and mistake smaller pieces for food (Wagner & Lambert 2018, 11). Secondly, after many years of floating in harsh ocean conditions, this gear breaks down into smaller segments. Waves cause the abrasion of fishing nets when the nets come in contact with sharper objects or other waste (Da Ros et al. 2016). In addition, the fragmentation of the fishing gear results not only in microplastics floating on the surface, but also sinking into deeper levels of the ocean (Villarubia-Gomez et al. 2018). Once these fishing nets release microplastics, it is unfeasible to remove them from oceans, seas and lakes.

The nets used in bottom trawling pose a serious threat to ocean floors. NOAA (2019) defines bottom trawling as a fishing practice where the net is dragged along the sea floor in order to catch fish. This is not only highly damaging to the sea floor, but also causes nets to fragment while in contact with harder or sharper objects (Marine Conservation Institute 2019).

According to Andrady (2011), the photo-degradation and thermal degradation of large plastic items into microplastics in the marine environment is highly unlikely; moreover, most degradation of macrodebris under these conditions occurs on beaches. However, there are many environmental and operational problems that arise during fishing which cause the tearing of fishing nets. When nets are dragged along uneven and harsh bottoms, or are entangled with other objects, they may tear (Macfadyen et al. 2009). Older gear is also more susceptible to tearing. Marine organisms can cause damage to existing plastic debris, resulting in the disintegration of the debris (FAO 2016).

Another problem is the chemical and mechanical deterioration of nets because of UV radiation (Sebille et al. 2015). This photo-oxidative degradation has been studied (Meenakumari & Radhalakshmi 1988) under induced UV light exposure. Six commercial fishing nets made out of nylon were examined. The results showed clearly that the nylon fishing nets underwent a loss of mechanical properties (Meenakumari & Radhalakshmi 1988).

Microplastic is estimated to account for 8% of the total mass of the Great Pacific Garbage Patch (Lebreton et al. 2018). In addition, according to Lebreton et al. (2018) at least 46% of this waste originates from fishing activities. The fishing activity in the Pacific Ocean has increased, and fishers in this region are more likely to discard their damaged fishing nets rather than collect them and bring them back to shore (Montarsolo et al. 2018). Therefore, discarded nets in oceans will remain for an extensive period of time, but simultaneously they slowly wear out and generate microplastics.

3.3.2 New gear technology

Macfadyen et al. (2009) suggest that fishing gear technology should be improved to combat the negative impacts of ALDFG. The use of biodegradable plastics has increased, and it is thought that biodegradable materials could be implemented as a base material for fishing gear (Kim et al. 2016). However, considering the problem of the weathering of fishing gear into microplastics, the solution may not be biodegradable plastics. This is because most of these types of plastics have added substances that further enhance the degradation process. These are called oxo-degradable plastics (Järvinen 2017, 217), and they break down into microplastics, but not into any smaller particles.

Gear innovations should be supported and encouraged at national and international levels (Kaiser 2014) to ensure more ecological and sustainable gear and net production. Since these potentially new fishing nets would at first be distinctly more expensive (FAO 2016; Valdermarsen & Suuronen 2003; Marzotto 2019), and even more difficult to control, much effort should be put into the design of new fishing gear (Valdermarsen & Suuronen 2003). Before fishers are willing to adopt the use of ecological fishing nets, the cost-effectiveness of using new gear needs to be ensured, and fishing techniques need to be improved (Wilcox et al. 2016). Increased costs result in lower earnings. FAO (2016) also recommends advancement in technology with an emphasis on environmentally friendly and biodegradable materials. However, the weaker structure of ecological materials results in more frequent gear replacement.

3.4 Linen

3.4.1 Qualities of linen

Linen is widely used as a textile and made from the flax plant. Flax is considered one of the oldest and historically significant cultivated plants (Hukkinen 1984, 9). Currently, interest in natural fibers is growing (Hirvi et al. 1990). This natural fiber is, in many ways, ecofriendly because it retains and stores carbon dioxide (Marzotto 2019). By itself, it is harmless to human health unless it is treated with certain chemicals. Concern over the environment combined with better awareness of materials has allowed for a new supply of natural fibers in products (Pasila et al. 1999). The costs of manufacturing natural fibers are still quite high, however, making their use unfavorable in many sectors.

Linen has great water absorption qualities, but it is also quick to dry (Hukkinen 1995, 14). The fabric repels dirt and bacteria, and compared with its natural substitute, cotton, dirt is easier to remove from linen (Hukkinen 1984, 17). In many respects, it is more suitable than cotton. In addition, flax requires significantly less water to grow than cotton, leading to savings of 650,000 cubic millimeters of water a year because of zero irrigation needed in its cultivation phase (Marzotto 2019).

The textile also holds a high tensile strength, which makes it a stronger textile than cotton (Hukkinen 1984, 17). The high fabric strength does make linen stiff to handle, nevertheless this allows it to be used for resistance purposes (Hukkinen 1995, 14). If linen is treated carefully during production phases, however, it does not lose any of its qualities (Marzotto 2019). Consequently, if some problem occurs during the processing of the fiber, the textile becomes unsuitable for use and is unrepairable at a later stage of production (Pasila et al. 1999). Linen has the potential to be used in manufacturing, and for technical and industrial purposes (Hirvi et al. 1990). Linen itself is durable under light and photo conditions, and this leads to it aging at a slow rate (Hirvi et al. 1990).

3.4.2 Linen as an alternative material to standard nets

Marzotto is a company based in Italy producing linen and other textiles. According to the company, in recent years, there has been notable interest in linen from both the producer and consumer side. This has led Marzotto to create new uses for the textile in different hi-tech products.

Linen is 100% biodegradable and recyclable. Given these properties, Marzotto is collaborating with another company to produce fishing nets made with linen. As of now, the focus of the production is on fishing nets for farming mussels. This falls under the EU’s Common Fisheries Policy (CFP) goal of sustainable aquaculture (European Commission 2019b).

Under laboratory conditions, the linen yarn did not lose any of its properties (Marzotto 2019). One of the important properties, especially in aquaculture, is how easily the material may tear. The linen net did not exhibit any tearing after 7 months of being immersed in sea water because the textile has a special mesh breaking load.

Additionally, during the trial run, the linen net did not demonstrate any change in performance when immersed in saline water. The net does, however, weigh more while wet, approximately 120% higher.

4 Data and methods

The previous chapters have provided important background information for the research question as to why it is important to study the economic factors of linen nets. In this section, I explain the theoretical framework and empirical research part of the study. The chapter begins with presenting the data and explaining from where the values of the variables used in the model have been retrieved.

4.1 Data on linen nets and standard nets

The data used to form the variables are presented in Table 1 (see Section 5.1). The data on the Finnish fishing fleet are retrieved from the European Commission's Scientific, Technical and Economic Committee for Fisheries report (STECF 2018). The recent, plenary information is from the year 2016. According to the Annual Economic Report (AER), the total number of all active vessels registered in Finland was 1,593. The total catch in 2016 came to 149,400,000 in terms of kilograms. The value of this catch in euros was 39,500,000.

Luke (2017) has provided the number of registered companies in both the small-scale fisheries (SCF) and large-scale fleet (LSF). There were 1,530 small-scale fishing vessels and the remaining 63 were large-scale fishing vessels. On large scale fleet, there are one to four people employed compared to one person working on smaller vessels (SAKL 2019a).

The EU publication (STECF 2018) reports the total wages and salaries of the crew which were €4,700,000, respectively. The energy costs, which mainly consist of fuel, was €8,400,000 and the repair and maintenance costs were €3,600,000. The total costs also include other variable costs and other non-variable costs, which amounted to €2,200,000 and €4,200,000. There is an annual depreciation cost which came to €14,900,000 in 2016.

Information for production costs and prices for the linen nets were partially based on expert opinions from the company Marzotto (see Section 3.4.2). However, the numbers have been adjusted to fit with this particular model. It is assumed in the model that costs of producing a linen net are higher than the costs to produce a standard nylon net, and the reasonable unit prices of linen nets are therefore higher, too. Equipment and gear costs are provided by Finland's Professional Fishers Association (SAKL 2019a).

The rotation of a standard net is between one and three years, depending on damages (SAKL 2019a). The durability evaluated for the linen nets are based on expert opinion. The interest rate used is 0.05, based on Holma, Lindroos and Oinonen (2014) and Kulmala, Laukkanen and Michielsens (2008) research papers, both on the economics of salmon fishery.

4.2 Modeling

4.2.1 Theoretical premises of a numerical analysis

To describe the decision-making of a fishing company, I use a rotation model, typically used in forest economics (Amacher, Ollikainen & Koskela 2009, 225). In this case, I use it to describe the fishing enterprises' problem of an optimal renewing cycle of fishing nets. In this section, the decision-making related to the renewal of fishing nets is formalized. Both a private-agent problem and a social-planner problem are formulated. The decisions concern the timing of fishing net renewal. As these decisions go in cycles, the problem can be presented within an optimal rotation framework with infinite time horizon.

A private fishing company operating with plastic nets maximizes its net present income as follows:

$$PNPV_{plastic} = \underset{T}{Max}\left[pq_0 + \sum_{t=1}^{T} \left(\frac{b_{plastic}}{1+r} \right)^t pq_t - C_{plastic} \right] \frac{(1+r)^T}{(1+r)^T - 1}$$

Where:

p=unit price of fish catch

q_0=quantity of fish catch with a new net

$b_{plastic}$= periodic plastic net decay rate

$b^t q_t$ =quantity of fish catch with t-period old net

C=costs of plastic fishing net user

r=interest rate

C in this case is all costs related to fishing. These costs are, besides net renewal costs for t=0, t=T, t=2T, etc., periodic discounted labor costs, maintenance and repair costs, capital costs, energy costs, and also other variable and non-variable costs.

Alternatively, the private agent can choose a non-plastic, natural linen-fiber net. In this case, the private agent's problem is the following:

$$PNPV_{linen} = \underset{T}{Max}\left[pq_0 + \sum_{t=1}^{T}\left(\frac{b_{linen}}{1+r}\right)^t pq_t - C_{linen} + s_t \right]\frac{(1+r)^T}{(1+r)^T - 1}$$

Where, additionally, now:

b_{linen} = periodic linen net decay rate

$(b_{linen})^t q_t$ = quantity of fish catch with t-period old linen net

C_{linen} = costs of linen fishing net user

s_t = possible subsidy paid for a linen net user

The social planner's problem for the use of a plastic net is the following:

$$SNPV_{plastic} = \underset{T}{Max}\left[pq_0 + \sum_{t=1}^{T}\left(\frac{b_{plastic}}{1+r}\right)^t pq_t - C_{plastic} - damage_t \right]\frac{(1+r)^T}{(1+r)^T - 1}$$

Where *damage* is the value of the ecological damage caused by using a plastic net, deserted into maritime ecosystems.

Typically $b_{linen}>b_{plastic}$ and $c_{linen}>c_{plastic}$, i.e., linen nets cost more and wear out more rapidly than do the plastic nets (SAKL 2019a). This implies that $PNPV_{linen}<PNPV_{plastic}$, meaning that the profitability of using linen nets is smaller than the profitability of using plastic nets. To compensate for this, the social planner may want to subsidize the use of linen nets, assuming that linen nets do not cause a negative externality in terms of ecosystem damages.

4.2.2 Model application

The aim is to determine a subsidy level that would make the private companies indifferent between choosing a plastic net or a linen net. This is a subsidy level that makes the profitability of the linen net users equal to that of the plastic net users. This subsidy level can then be related to the information about the ecological externalities of using plastic nets, i.e. to the damage faced by the social planner.

The model is run, using MatLab (R2017b), and based on the data presented above, separately for two segments of the Finnish fishing fleet, small-scale coastal fisheries and the large-scale fleet. The profit maximization solutions are determined with average firm-level data. Therefore, for example, the catch volume in Table 1 (see Section 5.1) is divided by the number of vessels. Subsidy levels are obtained by multiplying the average profit differences of plastic and linen net users with the total number of vessels operating in each segment. No exact data exist for linen net prices. Therefore, analyses were carried out with a range of price levels for linen nets.

The model applications for the two segments of fisheries were needed as these segments differ considerably from each other. The use of an average of the SCF and LSF would give an unrealistic picture because this would skew the results. For example, the average catch prices for SCF are much higher than for the LSF because of differences in the fish species (Luke 2017). The large 63 trawlers are responsible for two-thirds of the total catch but their customers are mainly fur producers and fish farms cultivating trout and salmon, and exports (STECF 2018; Luke 2017).

Solving the optimal private rotation problems for both plastic and linen nets will give $PNPV_{plastic}$ and $PNPV_{linen}$, where the value of the linen net is first assumed without the subsidy policy. A subsidy has to be solved in the private problems in such a way that $PNPV_{plastic} = PNPV_{linen}$. This is the level of the subsidy that makes the private agent indifferent between using a plastic net or a linen net.

I will interpret the above subsidy level as the minimum level externality value that would justify the subsidy policy for the social planner.

4.3 Sensitivity analysis in the case of uncertainty

Sensitivity analysis was carried out, besides with respect to the linen net price level, also with respect to other parameter values. This is needed to evaluate the robustness of the results, as well as compensating for likely deficiencies in the reliability of expert opinions.

The objective of sensitivity analysis is to find how the target function, or output, is most subject to change under which variables (Saltelli, Tarantola, Campolongo & Ratto 2004, 42). The main focus in the sensitivity analysis for this study is on changing the cost and price parameters of the standard nylon fishing net and the linen net while keeping all other variables constant. The cost and price parameters require the most assessment as they remain the most uncertain variables.

5 Results

5.1 Baselines and ranges for displaying the results

In this section the results of the numerical model runs are explained. To illustrate the impact of linen net purchasing prices, a price range was set separately for large-scale fisheries and for small-scale fisheries. Baselines for the prices of fish are based on average prices calculated from figures in Table 1.

	Small-scale coastal fishery (SCF)	**Large-scale fleet (LSF)**	**SCF & LSF**
Costs, € (million)			
Wages & salaries	0.6	4.1	4.7
(Unpaid)	1.2	0.6	1.8
Energy	0.9	7.5	8.4
Repair & maintenance	1.2	2.4	3.6
Other variable costs	0.7	1.5	2.2
Other non-variable costs	1.2	3.0	4.2
Depreciation	5.9	9.0	14.9
Number of vessels, active	1 530	63	1 593
Catch volume, kg (million)	9.3	148.1	149.4
Catch value, € (million)	8.6	30.9	39.5
Price of fishing net, €	30-100	10 000-50 000	
Number of nets per company	50-100	1	
Decay rate, b	0.8-0.9	0.8-0.9	

Table 1. Data used for Finnish small-scale coastal fisheries and large-scale fleet. Sources: STECF (2018) and SAKL (2019a).

Below, Figures 1 and 2 illustrate the effects that fish prices have on the profits for the large-scale and for the small-scale fishing companies. These figures reflect the operational environment of the industry. Figures 3 to 6 display the impacts of net prices on the profitability of the fishing industry using four rotations for the net renewals. Thus, they illustrate the profit sensitivity with respect to using different net renewal rotations. Figures 7 and 8 show the needed subsidy level for trawl net users and for small fisheries. Lastly, a WTP is calculated for consumers that prefer seafood caught with the more ecological nets.

5.2 Fish prices and profits

5.2.1 Large-scale fisheries

Next, by changing the values of the price of fish (€/kg) from the starting price in 2016 of 0.18 euros, we obtain the corresponding value for the profits in euros (€).

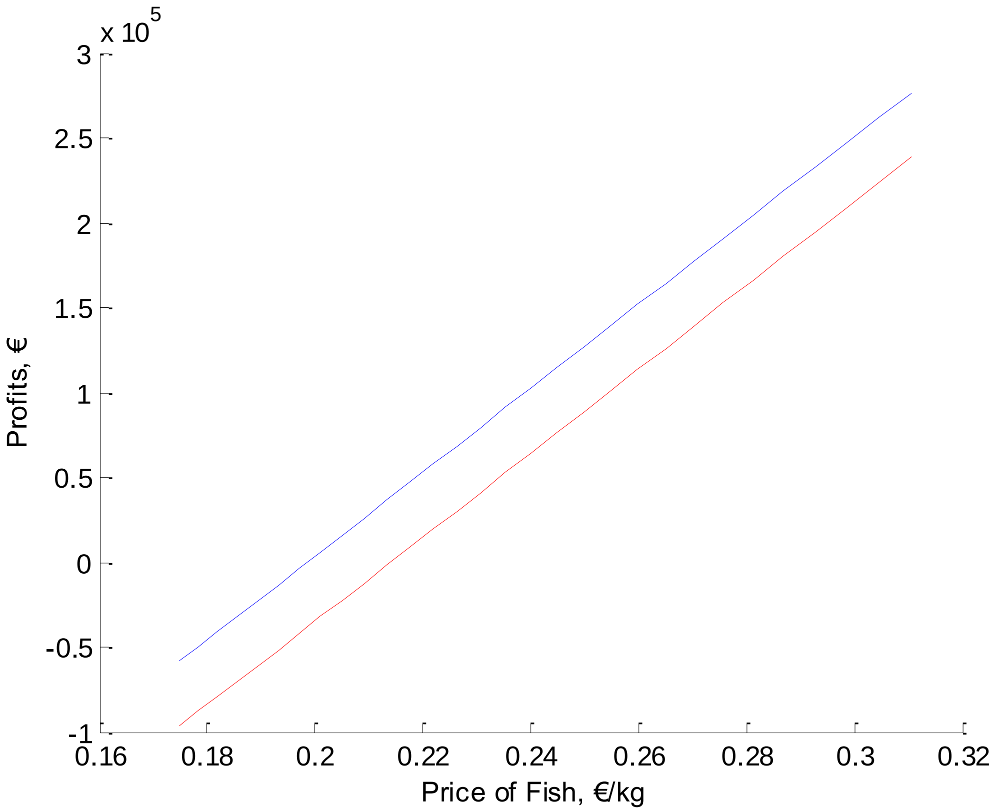

Figure 1. Impacts of price of fish on profits for large-scale fishing companies. Blue is for plastic net users. Red is for linen net users.

The blue curve in Figure 1 demonstrates the impact of the fish price on the profitability in the case of plastic net users and the lower, red curve, shows the same for linen net users. As can be seen, the profits are highly sensitive to the price of the catches. Profitability seems to be negative for the plastic net fishers with the prices of fish, 0.18€/kg, in 2016. At the level of about 0.20€/kg, however, the profits are at a breakeven point and profits turn positive. The breakeven point for fishers using a linen net is about 0.22€/kg.

The business seems to be very dependent on the catch prices. With the parameter values used to draw this figure the optimal rotation within the used price range was one for both the plastic net and linen net users.

5.2.2 Small-scale fisheries

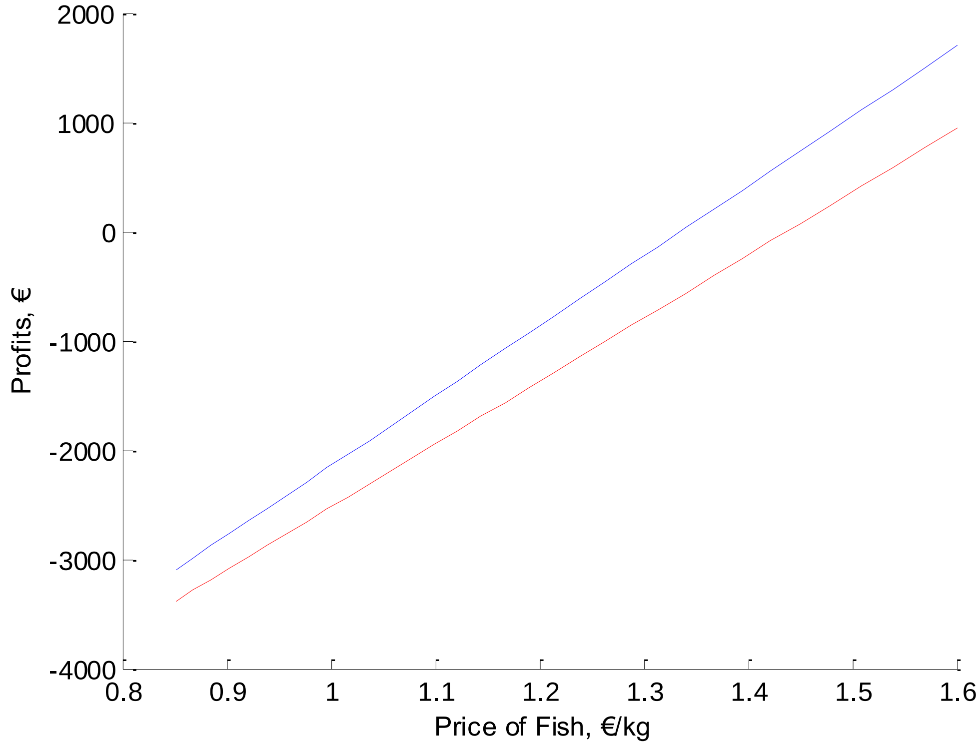

Figure 2. Impacts of price of fish on profits for small-scale fishing companies. Blue is for plastic net users. Red is for linen net users.

In Figure 2, the blue curve denotes the values for plastic net users, and the red curve denotes the values for linen net users. For plastic net users the optimal rotation was one year, and for the linen net users the optimal rotation was two years. The profit differences between the two nets increase with the catch prices.

The profits were negative with prices of fish below 1.30€/kg for the plastic net users, and below 1.45€/kg for the linen net users. Thus, the profits were negative in 2016, which meant that the fishers were unable to cover all their capital costs. The industry, hence, was unprofitable.

5.3 Linen net prices and the NPV

The study next looks at the question of how the impacts of net prices on profits vary when using different rotations for net renewal. Additionally, the effects of two net decay rates are illustrated. Again, the figures are computed separately for LSF and SCF as the net prices differ considerably.

5.3.1 Linen net prices and profits of LSF

In Figures 3 and 4, the curves are downward sloping.

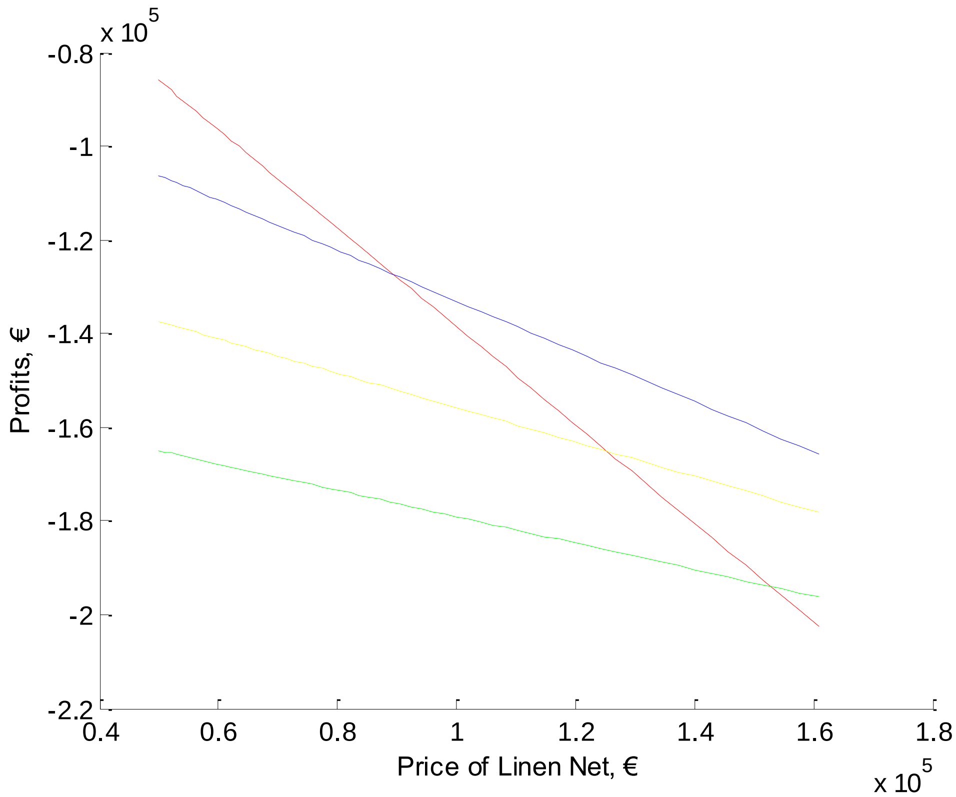

Figure 3. Impact of trawler net price on the profits of large fishing companies with different net renewal rotations. Red=1-year rotation, blue=2-year rotation, yellow=3-year rotation, green=4-year rotation. Net decay rate b=0.8.

Figure 3 indicates that the net prices play an important role in the profitability of fishing companies. Furthermore, the figure shows that the rotation of the nets affects the profitability considerably.

Specifically, according to the figure, when the linen net price is under about €90,000, the optimal rotation of the net is one year. Beyond this level, the optimal renewal cycle is two years. However, the optimal rotation is quite sensitive to the net decay rate. This is evident by comparing Figure 3 to Figure 4; in the former the net decay rate b is assumed to be 0.8, whereas in Figure 4 it is assumed to be 0.9.

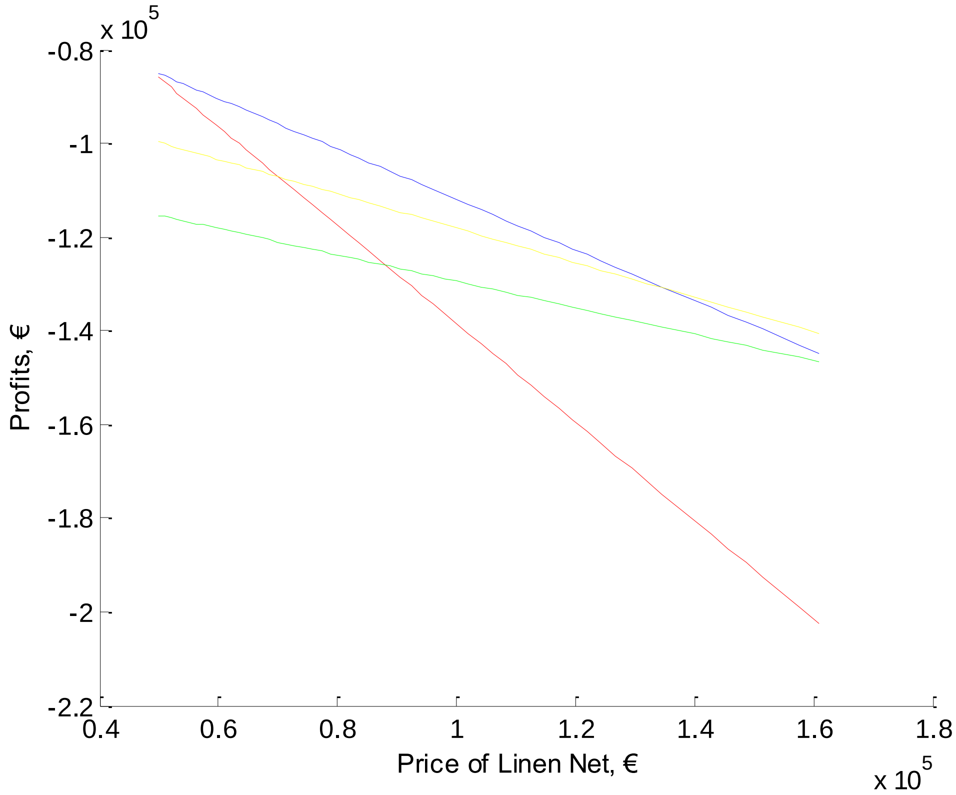

Figure 4. Impact of trawler net price on the profits of large fishing companies with different net renewal rotations. Red=1-year rotation, blue=2-year rotation, yellow=3-year rotation, green=4-year rotation. Net decay rate b=0.9.

The decay rate is unknown, and hence changing it, we can see how the parameter affects the outcomes. Figure 4 has a slower decay rate compared to Figure 3. In Figure 4, the optimal rotation is two years with lower linen trawl net prices, and three years with higher fishing net prices. The changing point of the rotations is approximately €140,000 which is when the rotation of three years becomes the most profitable cycle.

5.3.2 Linen net prices and profits of SCF

Figures 5 and 6 are for the smaller fishers in the industry and they illustrate the effects of linen net prices, rotation periods and the net decay rate, and the effects on profits.

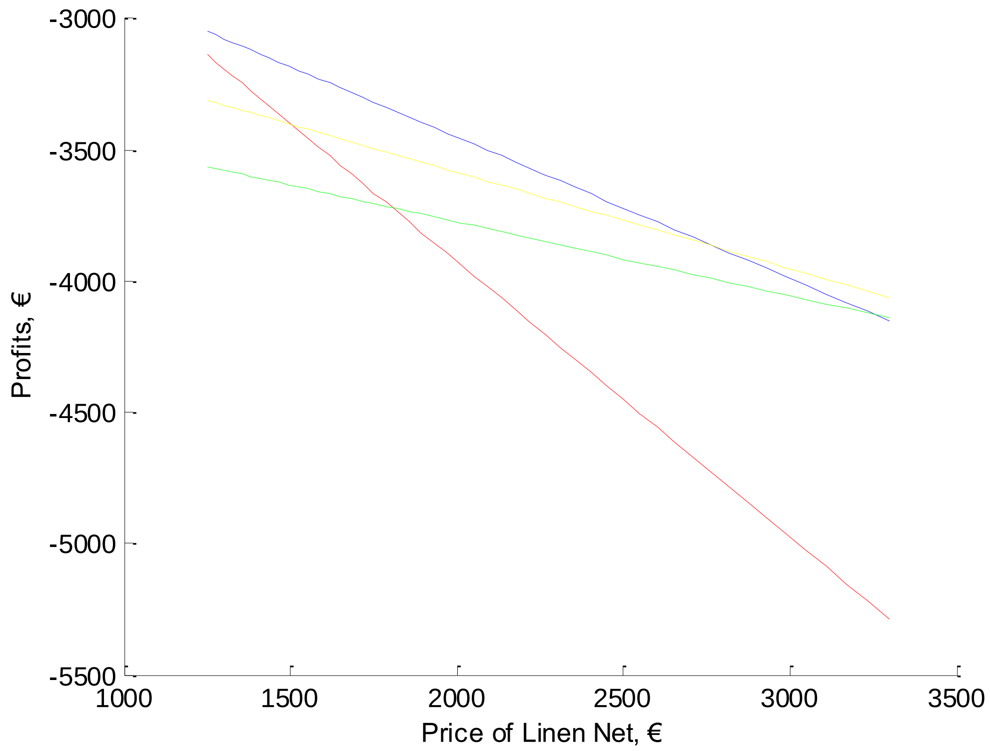

Figure 5. Impact of linen net-set price on the profits of small fishing companies with different net renewal rotations. Red=1-year rotation, blue=2-year rotation, yellow=3-year rotation, green=4-year rotation. Net decay rate b=0.8.

With the faster decay rate of 0.8, rotation two is the most profitable up to the point of the linen net value of approximately €2,700, after which rotation three becomes the most profitable.

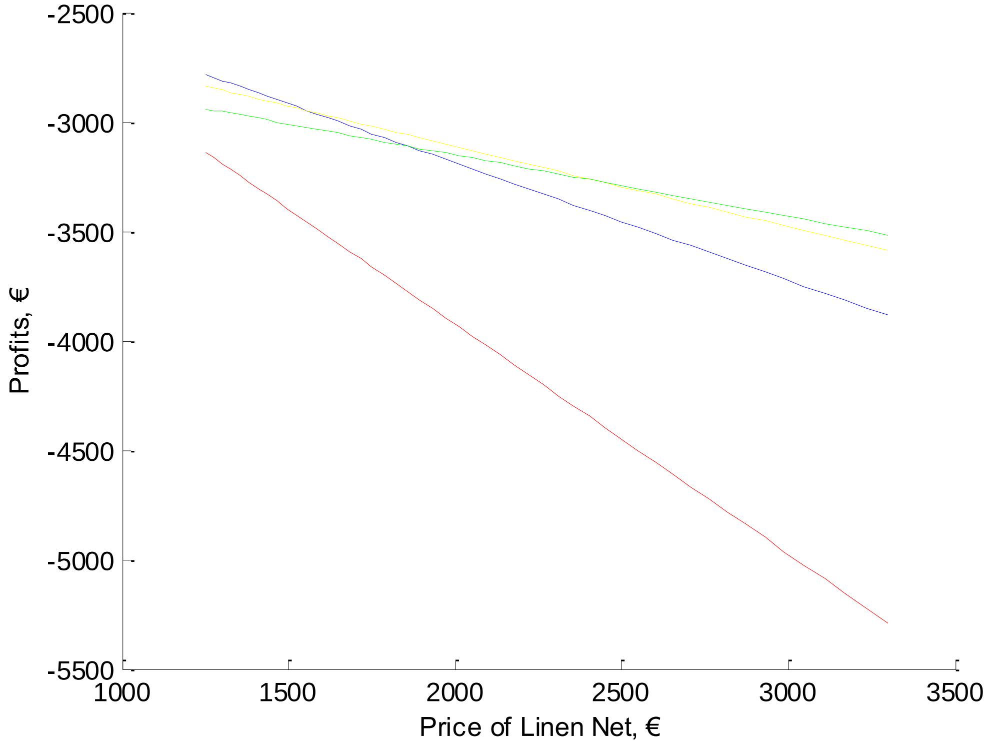

Figure 6. Impact of linen net-set price on the profits of small fishing companies with different net renewal rotations. Red=1-year rotation, blue=2-year rotation, yellow=3-year rotation, green=4-year rotation. Net decay rate b=0.9.

With a slower decay rate of 0.9, and with a lower linen net price, the 2-year, 3-year and 4-year rotation periods are almost indifferent as renewal cycles. When the linen net price is under €1,500, rotation period 2 is the most profitable, but at a price over €1,500 the third rotation period becomes the most profitable up to approximately €2,800. At this price, a 4-year rotation period becomes the most profitable.

For the SCF, renewing a linen net every year is unprofitable at the two given decay rates.

5.4 Subsidy level

The subsidy level is calculated separately for the trawl net fishers industry and for the small-scale fishers industry. A subsidy level is computed for the parameter values that have been used for the linen net users above. A subsidy level is also calculated for linen net users that experience a 10% increase in labor costs related to repairing and fixing linen nets.

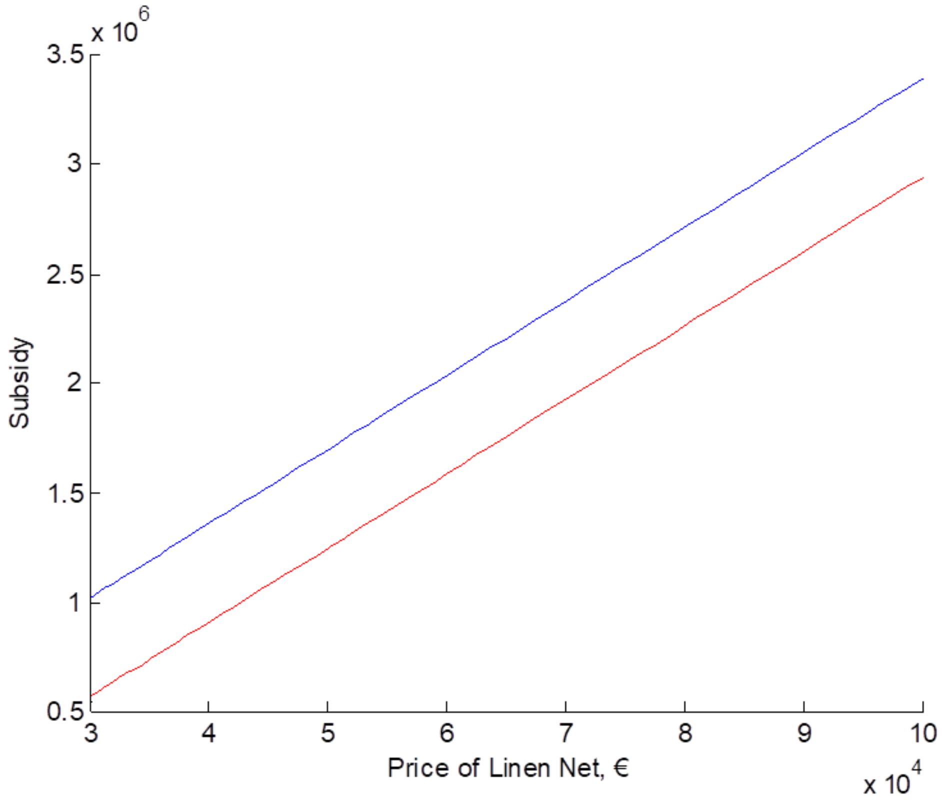

Figure 7. Total subsidy level for large trawl net users. Blue is subsidy with extra labor cost. Red is subsidy without extra labor cost.

The subsidy is calculated based on the difference in averages of profits for linen net users and for nylon net users, after which the difference is then multiplied by the number of vessels. Figure 7 shows the total subsidy level needed for the entire trawl net users sector. The starting price of a linen trawl net used here is €30,000. The horizontal axis shows different prices of linen nets and the vertical axis shows the needed subsidy level for the different prices of linen nets. At a price of €30,000, the industry of the linen trawl net users would need a subsidy allocation of about €1 million. The lines are naturally trending upwards: as the price of linen nets rises, the needed subsidy level rises, too.

The red line depicts the subsidy for the linen net users without the extra labor cost assuming a technological advancement for the linen net, meaning there is no need for extra work on linen nets. The subsidy without the extra labor cost is approximately half that of the subsidy level with the 10% additional labor cost.

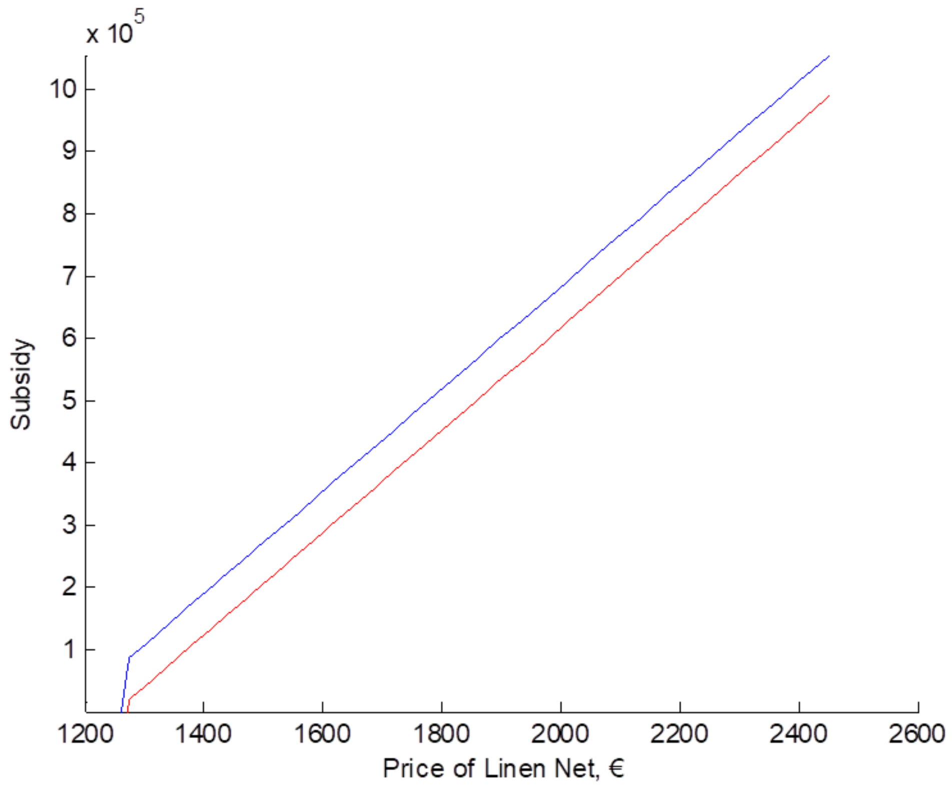

Figure 8. Total subsidy level for small-coastal fisheries. Blue is subsidy with extra labor cost. Red is subsidy without extra labor cost.

Figure 8 depicts the needed subsidy for the small-scale fishers. The starting price of the linen net here is set at €1,250. The blue line again indicates the subsidy for linen net users with a 10% extra labor cost, while the red line is the needed subsidy level without taking into account this labor cost increase. The numbers are based on the optimal rotations, and the differences in the profits of linen net fishers and plastic net fishers. The optimal rotation for the plastic nets is two, and the optimal rotation for the linen nets is also two.

The subsidy, as can be seen, is very dependent on how low or high the prices of the nets are. The subsidy is very elastic in the case of small-scale fisheries compared to the large-scale fisheries. As seen in Figure 8, when the price of the linen net doubles, the required subsidy is ten-fold. Hence, the elasticity is 5. At the price level of about €2,400, the subsidy would rise to one million euros.

5.5 Consumers' willingness-to-pay

An alternative to a government-based subsidy for linen net users would be an increased willingness-to-pay (WTP) for ecologically caught fish by seafood consumers. In other words, we can ask how much higher would the price of the end product have to be so that a producer using a linen net reaps the same profits as a plastic net user. How much more do consumers have to pay in euros per kilogram in order for the fisher using linen nets to match the profits of plastic net users?

The WTP for consumers using the produce fished, e.g. Baltic herring, by the large trawl net users is obtained from Figure 1 by calculating the difference in profits for the plastic net users and for the linen net users. To compensate for this profit loss for the linen trawl net users, the WTP would have to be approximately 9.9%.

Figure 2 shows the differences between the graphs corresponding to the WTP for consumers of fish caught by the small-scale fisheries, e.g. wild-caught salmon. Consumers would have to pay 7.8% higher prices for the knowledge that their seafood has been caught with ecological fishing nets.

6 Conclusions and discussion

In this study, I provided a framework for numerical analysis to evaluate the possible subsidies that could be applied to make professional fishing enterprises use ecological nets. I contributed to the literature in linking the decision-making of fishing enterprises to the social benefits of moving from currently used plastic nets to more ecological fishing nets.

In the previous chapter the results of the rotation model were explained in detail. This chapter synthesizes the motives for and importance of reducing plastic debris in waterbodies. The chapter continues with a discussion on different policy instrument options. It also presents an overview of existing policies and initiatives in the European Union that are partially comparable with this topic. The conclusions of the thesis are presented last.

6.1 Human concern over plastics

Microplastics are the result of larger plastic items dissolving and disintegrating. Microplastic is defined as a synthetic particle under 5 mm in size (FAO 2016; NOAA 2018). Since plastics are made from various chemicals and oil, they cause harm to living organisms if ingested (GESAMP 2015; Wagner & Lambert 2018, 11; Chiba et al. 2018).

Humans' awareness of the dangers and environmental problems of plastics is growing. Microplastics are increasingly studied by numerous research groups in different countries, and they are found in all parts of ecosystems including soil and water (EU Commission 2019; Hammer et al. 2012). The most extensive studies conducted so far are on the effects microplastics have on the reproduction and reproductive system of bivalves (Lusher et al. 2017; Browne et al. 2008).

Plastic garbage in waters consists of many products, including bags and bottles. However, it is estimated that approximately 50% of plastic waste consists of fishing equipment, at least in ocean gyres (Lebreton et al. 2018; Hammer et al. 2012; Chen et al. 2018; Derraik 2002). Most fishing gear is synthetically made from plastic materials. ALDFG (abandoned, lost or otherwise discarded fishing gear) poses a potential threat to the surrounding environment, not only because of ghost fishing, but also because it will persist for hundreds of years of disintegration into smaller pieces (Villarubia-Gomez et al. 2018; Macfadyen et al. 2009), which are eventually classified as microplastics. The effect of microplastics on plants, organisms and all wildlife is profound.

I have presented an alternative, natural material for fishing nets. The Italian company Marzotto is still in the pilot phase of examining linen fishing nets as new gear technology for solving the microplastic problem. Linen is a natural fiber and hence would completely decompose in the environment. However, there are several disadvantages that need to be tackled. One is the weight and stiffness. Another problem is that these linen nets, too, might continue ghost fishing after being abandoned or lost in water for some years. Furthermore, when linen nets begin to decay, the fiber releases particles that marine organisms might wrongly perceive as food. Finally, the production and user costs related to linen fishing nets most likely exceed those of plastic nets for many years. Improvements in the design and manufacturing, as well as the funding, are needed.

6.2 The EU and existing projects

The EU Common Fisheries Policy states that it aims to "ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens" (European Commission 2019b). Underlining the fact that fishing is supposed to ensure healthy food, the mitigation of microplastics in seafood is a crucial element to consider. Several policies and projects have already been implemented in the EU to ban the improper discarding of gear, and to create alternative and recyclable uses of aged fishing gear.

The European Commission is introducing a new act to retrieve all types of abandoned fishing gear back to shore, so that this equipment could then be properly recycled and reused. The core part of this new policy complements existing ones, but from now on, will have the producers of plastic fishing gear cover the costs of bringing the abandoned gear back to harbors and ports (EU Commission 2018).

Iceland has its own ongoing project, called the Circular Ocean, which promotes the reuse and new sustainable use of former fishing gear. The project aims especially to attract entrepreneurs to step forward and take initiative in developing new, recycled products from collected fishing nets (Circular Ocean 2019).

In Finland, SYKE (Finnish Environment Institute) and SAKL (Finnish Professional Fishermen's Association) collaborate with other agents in the fishing sector to survey how many ghost fishing nets exist in Finland’s coastal regions. The project, KAPYYSI, also focuses on the removal of these hazardous fishing nets with the help of local fishers (SYKE 2019; SAKL 2019b).

These projects indicate the seriousness of the problems fishing nets pose and that the issue is being worked on already. The emphasis has been on what to do with aged and used gear. Also, many new fishing net technologies focus on reducing the bycatch and reducing other sea animals being caught in nets (Holma et al. 2014). Could similar projects and policies be created to encourage the use of environmentally friendly nets? This is one possible way to reduce the amount of plastics and especially the microplastic build-up in seas, so theoretically projects could be launched to address this global problem.

Policy instruments could be implemented to tackle the increasing problem of microplastics. Among them are taxes and subsidies. A higher tax could be imposed on plastic products or a subsidy could be used for more ecological options, for example linen nets. This subsidy-based policy instrument could be an incentive for entrepreneurs to prefer their use. In this study, I focused on analyzing the impacts of subsidies. Taxing plastic products was not analyzed in this model but it could be examined in addition to the subsidy-based policy instrument and a comparative analysis between taxes and subsidies could be carried out.

When reflecting the model used in this study and the obtained subsidy levels, a few remarks are to be considered. First of all, it is an interesting question whether the subsidy could be fixed on the European Union level and then be distributed to the member states, for example based on fishing activity, number of vessels or number of fishing nets. Alternatively, the subsidy could be decided on a national level. In this case, the subsidy could be allocated to the linen net producer or, as assumed in the model applied in this study, for the fisher who is adopting this ecological gear. If the subsidy were curated at a national level, it would be aligned with the Common Fisheries Policy’s latest position on allowing its member states to have more self-government on their decision-making and laws concerning fisheries (European Commission 2019b).

An alternative to a subsidy, which was presented in the outcomes of Chapter 5, would be a voluntary arrangement based on consumers’ willingness-to-pay. The WTP could be achieved through the raise of awareness in consumers. This means that consumers would be enlightened that certain seafood products are cultured or caught with non-plastic nets, and thus a higher price for these end products would be charged. This could potentially narrow the gap of linen net and nylon net fishers' profits in a way that a subsidy would not be needed. The results obtained in this study imply that the WTP required to close the gap in profitability between fishing using traditional and ecological fishing gear could be fairly moderate, between 7% and 10% of the end-product price level.

Another point to consider is the scale at which the negative externality, caused by plastic fishing gear, should be examined: at a global scale taking into account all oceans and seas, or at a regional scale, representing certain geographical locations, e.g. seas in Europe or only the Baltic Sea. In this study, the externality was looked into at a national level, concentrating on the cost differences within the Finnish fishing fleet. Hence, the externality related to plastic nets in this case is only for a small area in the Baltic Sea. A future study could extend the analysis carried out here to cover multiple European countries and the respective waterbodies.

6.3 Concluding remarks

In this study, I focused on the possibility of the professional Finnish fishers changing from synthetic material fishing nets to linen nets. In particular, my interest was to calculate how much this would cost with a subsidy. The total subsidy for both the LSF and SCF is from a range of €1.1 million to €4.5 million, and depending on the price of the linen net which will be depending on the technological development in the future.

This range of a subsidy can be related to the negative externality caused by the Finnish fishing fleet in the Baltic Sea region. At least at the lower end of the subsidy range, it seems highly likely that the value of the negative externality is higher than the subsidies needed to abolish the externality. The negative externality is caused by the fishers leaving their worn out fishing gear at the bottom of the sea where they cause microplastic leakage and ecological damage to the ecosystem, and possibly giving rise to human health issues. However, no such estimate exists for the value of the negative externality. Valuation of this negative externality caused by microplastics could be an area of future studies.

The WTPs of 7.8% and 9.9% seem to be moderate and could be further examined by research surveys geared towards the general public or the professional wholesale purchasers of the pelagic catch in the Baltic (i.e. herring and sprat).

The transition into the use of natural materials with seafood directed for consumers would improve the image in front of the grand public as compared to the farm-based fish produce, such as salmon and rainbow trout, and it could reflect positively on the demand and price level of the wild-caught fish, and also reflect positively on the profitability of the business. The fishing industry is operating at a very low profitability level. Therefore, in order for them to change to more ecological fishing gear, a subsidy would most likely be necessary, or they would need to be able to charge a higher price for the catch caught with ecological gear.

This study also contributed in providing an analytic and numerical framework to study the economics of fishing entrepreneurs. A rotation type of model was introduced to describe the behavior of fishing companies. This framework could be applied in further research by utilizing EU data and comparing the situation of the fishing industry in EU countries.

The subsidy for the use of more ecological nets, as suggested in this study, could be applicable. Furthermore, a subsidy-based policy could most likely be imposed with reasonable transaction costs. Naturally, such a policy would necessitate new production lines by current producers of nets in Finland and other countries.

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